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Performance of Non-Condensing Steam Turbine by Using Energy and Energy Analysis

Mrs. K.Lavanya, M.Tech
Assistant Professor,
Department of Mechanical Engineering,
Sanketika Vidya Parishad Engineering College,
P.M.Palem, Visakhapatnam.

B.Harikrishna Raju
B.E
Department of Mechanical Engineering,
Sanketika Vidya Parishad Engineering College,
P.M.Palem, Visakhapatnam.

ABSTRACT:

In the existing scenario most of electricity produced throughout the world is from steam power plants. Coal shares major chunk of fuels used to produce power in thermal power plants in India. Coal reserves are limited and present coal consumption rate is in increasing trend to full fill the power demand. Steam turbine is an excellent prime mover to convert heat energy of steam to mechanical energy. Of all heat engines and prime movers the steam turbine is nearest to the ideal and it is widely used in power plants and in all industries where power is needed for process. About 80% of electricity generation in the world is done by steam turbines. The objective of this work is to evaluate the performance of non-condensing steam turbine by using the energy analysis and energy analysis based on the first law of thermodynamics and second law of thermodynamics respectively. Energy analysis deals with quantity aspect whereas energy analysis deals with quality aspect in addition to quantity. In this analysis, energy efficiency, energy destruction, energy efficiency and turbine heat rate are evaluated based on the requirement of load demand.

KEYWORDS: ***Steam Turbine, Energy, Efficiency, Exergy.***

INTRODUCTION

A steam turbine is a mechanical device that converts thermal energy in pressurized steam into useful mechanical work.

Steam power plants are utilized for power demand in India. Coal is the major source of energy in these power plants. Coal shares major chunk of fuels used to produce power in thermal power plants in India. Coal reserves are limited and present coal consumption rate is in increasing trend to full fill the power demand[1].

Energy analysis conservation study is focused on energy efficiency. It is completely based on first law of thermodynamics which is normally used to analyze the energy utilization, but it doesn't use the quality aspect of energy. The energy of system is defined as the ratio of energy of output to the energy of input to the system. Exergy analysis deals with quality and quantity aspects of energy. It is completely based on second law of thermodynamics. It is a property that enables us to determine the useful work potential of given amount of energy at some specified state. It can specify where the process can be improved and therefore, it will signify what areas should be given consideration. Exergy provides us with a better understanding of processes for qualifying energy. Therefore, it would be better to use exergy to locate, qualify and quantify energy destruction.

Fig 1: Sectional View of Steam Turbine

Exergy can play an important role in strategic development of power plants and provision of use of instruction in existing power plant[2,3].

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Non-condensing Steam Turbine is a type of steam turbine which uses the high pressure steam for rotation of blades and then the steam leaves the turbine at the atmospheric pressure or lower pressure. This type of turbine is also known as back-pressure steam turbine. The pressure outlet steam depends on the load. The low pressure steam uses for processing and no steam is used for consideration. these turbines are mostly used in chemical industry, paper mills and desalination plants etc. These turbines acts as pressure reducing stations and at the same time provide reliable power for these plants[4].

In this steam turbine, the steam is expanded from inlet and continuously flow through the outlet. In this turbine there is no high pressure extraction but there is only low pressure extraction which is used for industrial process. In this process, we don't use condenser so that the remaining steam is released in atmospheric air. Steam turbine is usually analyzed by energy analysis which uses first law analysis but better understanding is attained when a more complete thermodynamic view is taken, which utilizes the second law of thermodynamics in conjunction with energy analysis, via exergy methods [5].

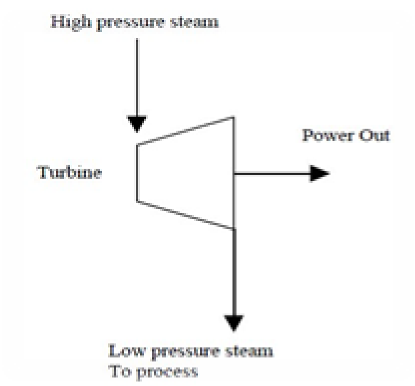

Fig 2: Flow Diagram of steam turbine

This study is focused on energy and exergy analysis of 6.1 MW Non-Condensing steam turbine. Therefore the energy efficiency, exergy efficiency and turbine heat rate are evaluated based on the requirement of load demand[6].

LITERATURE REVIEW

A.H.Rana et al.[1] was proposed on Energy and Exergy Analysis of Extraction cum Back Pressure Steam Turbine. In this analysis, energy efficiency, exergy efficiency, exergy destruction and turbine heat rate are evaluated at 70% and 85% maximum continuous rating (MCR) of steam turbine. Analysis shows that operating turbine at 85% MCR attract heat rate improvement by 17.01KJ/KWh, which reduces CO_2 emission by 26.89kg/h, SO_2 emission by 26.89kg/h and ash generation by 41.47 kg/day. Turbine exergy efficiency is lower than its energy efficiency as utilization of heat is at lower temperature than inlet. When Turbine MCR is increased from 70 to 85%, coal consumption is reduced by 16.46 kg/h and ash handling plant load is reduced by 41.47 kg/day. CO2 emission is reduced by 26.89 kg/h, while SO2 emission is reduced by 0.62 kg/h. Thus, it is more advantageous to run turbine at higher MCR.

Ivensunit rout et al.[2] was proposed on thermal analysis of steam turbine power plants. To improve the power output of the turbine, thermal efficiency and specific steam consumption in conventional steam power plants. Three cycles i.e. Regenerative cycle, super heater cycle and co-generation cycle are considered to formulate the data and obtain better results in steam turbine power plants. The power output of the turbine was highest in the co-generation in the steam plant as compared to the Regenerative stem plant and super heater steam plant with increase in turbine inlet temperature. The thermal efficiency of super heater steam plant is highest as compared to the regeneration and co-generation steam plants with increase in turbine inlet temperature. The specific steam consumption is least in co-generation steam plant as compared to the regenerative and super heater steam plant with the increase in turbine inlet temperature. Finally co-generation steam power plants are more efficient as compared to the conventional steam power plants. The turbine efficiency improves and the specific steam consumption is low. The low grade waste heats from the process heater are used for doing work and also generate power and electricity.

Pratap s more et al.[3] has been calculated the thermal analysis of energy and exergy of back pressure steam turbine in sugar co-generation Plant .Energy efficiency, exergy efficiency, exergy destruction , turbine heat rate are evaluated at 70% and 80% MCR(Maximum continuous rating) of back pressure steam turbine in sugar co-generation plant. This analysis shows that operating turbine at 85% MCR attract heat rate improvement by 17.01 kj/kwh. Turbine exergy efficiency is lower than its energy efficiency as utilization of heat is at lower temperature than inlet. Turbine exergy loss is 12.32% and 12.56% at 70% and 85% MCR, there is an improvement observed in turbine heat rate by 17.01kj/kwh.

A.Sudheer Reddy et al.[4]was explained about Analysis of Steam Turbines. In power generation mostly steam turbine is used because of its greater thermal efficiency and higher Power-to-weight ratio. Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator – about 80% of all electricity generation in the world is by use of steam turbines. In this project we have mainly discussed about the working process of a steam turbine. The thermal efficiency of a steam turbine is much higher than that of a steam engine. This paper has attempted to cover some of the issues related to Steam turbines which a designer should be aware of. It is hoped that this notes helps a working Engineer have a better insight into the various aspects of the Steam turbines, so that the related issues can be tackled with better knowledge and confidence. Anjali T H et al.[5] has theoretically experimented about analysis of efficiency at a thermal power plant. The objective of this work is to use the energy analysis and exergy analysis based on the first law of thermodynamics and second law of thermodynamics respectively, to identify the locations and magnitudes of losses in order to maximize the performance of a 15 MW thermal power plant in a paper mill, to evaluate the boiler, turbine and condenser efficiencies. The efficiency of components in the power plant is found out by using energy and exergy calculation. The overall efficiency of thermal power plant very less (13%) , then need an energy and exergy analysis in every component. finally the overall efficiency of a thermal power plant is increased by using energy and exergy analysis in every component.

Dev Kumar Pate let al.[6] has studied about how to improve steam turbine efficiency by use of Reheat Rankine Cycle. This paper contain the effect of operating condition of turbine, back pressure turbine inlet steam temperature and advantage of improving inlet steam temperature by reheat cycle on the efficiency of steam turbine and total energy production of power plant. In this paper it shows impact of operating conditions on steam turbines. Savings presented are for typical operating conditions. Huge benefits can be reaped by optimizing operating parameters, by minor modifications and even by replacing old in-efficient turbines.

P. RavindraKumar et al.[7]was proposed on steam turbine for power plant unit with super critical steam parameters, these parameters are considered by considering the steam turbine losses and pipe losses. The dependence of the efficiency of the unit on the isentropic efficiencies of individual turbine stages i.e. High Pressure Turbine (HPT), Intermediate Pressure Turbine (IPT), and Low Pressure Turbine (LPT) stages in a layout is considered. The computations show that the efficiency of the turbine plant should be 49 %, that of the boiler should be 93.66 %, and that of the power unit should be 46%. At the present time the use of the measures mentioned allows the following efficiency of the Turbines: 0.92 for HPT, 0.94 for IPT, and 0.9 for LPT, which corresponds to the world level.

INDUSTRIAL INVESTIGATION

WORKING PROCESS:

From the cogeneration plant, the fuel (generally coal of 45TPH) is burnt in a furnace and hot gasses are produced. These hot gasses come in contact with water vessel where the heat of these hot gases transfer to the water and consequently steam is produced in the boiler. As the high pressure steam coming from the boiler to

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the inlet of steam turbine which passes through the throttle governing.

In this process, 505 Woodward governor is used to control any process directly related to unit load and it is used for plant power control and it controls the turbine speed & the mechanical throttle governing. The throttle governing is used for passing the steam flow into the turbine. In this method steam is passed through a restricted passage thereby reducing its pressure across the governing valve. The flow rate is controlled using a partially opened steam control valve. There are three throttles governing of 30%, 70% &100%.First 30% throttle governing opens when it reaches to 0-4.4 MW.

Then 70% throttle governing opens when it reaches to 4.4-5.5 MW. Then 100% throttle governing opens when it reaches to 5.5-6.1 MW.When all the throttle valves get open the steam will fall on the turbine wheel and the steam gets decreased by 50%.The reduction in pressure leads to a throttling process in which the enthalpy of steam remains constant. The remaining 50% steam passes with high pressure into the turbine. High Pressure steam is used for rotation of impulse turbine blade and the turbine rotates with the speed of 8226rpmand the steam flows continuously to the reaction turbine blades, the flow of steam get decreased constantly. Thus the remaining steam backed up which is released in atmospheric air (or) send to industrial process.This turbine gauge with pressure switch cum transmitter panel helps for measuring the pressure values by using pressure gauges and temperature values by digital indicator. When the turbine is in running condition, the pressure and temperature values are noted down when it reaches to steady state (For Example: For full load the pressure value is $64 kg/cm^2$ and temperature is 485^oc). In this process, the thrust bearing is used to provide a positive axial location for the turbine rotors which is relative to the cylinders and journal bearing are used to retain the rotor system in its correct radial position, relative to the cylinders and it is used for turbine bearings and lubrication control. In this process, the lube oil is used for lubrication and to reduce the heat losses which are generated by turbine. The lube oil filter is used for oil purification. In this process, Auxiliary Oil Pump is used for turbine rolling start-up (for increasing full speed) and it is automatically closed and Main Oil Pressure takes over it. The Main oil pump (MOP) is the one that delivers all the oil requirements for the turbine-generator at high pressure during normal operation. It passes the lubrication oil to the lube oil cooler and the lube oil filter then passes the oil to turbine front and thrust bearings and then to the rear bearings and to the gear box and to the alternator front and rear bearing. When the bearing doesn’t receive lubrication oil in time to run the turbine in that case we use the Emergency oil pump. Emergency oil pump (EOP) runs on the battery for 20mins.It has a over head tank of 2000 litre. After running the turbine for certain amount of time, the lube oil which is used in the turbine process is collected back and send to oil cooler for oil temperature reduction.

After cooling process is done the lube oil is used again for turbine process. The Accumulator is used to control the oil pressure for maintaining constant pressure and it has nitrogen gas of 10kg. The turbine shaft which is connected to the gear box in which the pressure and kinetic energy is converted into mechanical energy then the gear box which is connected to the generator it converts the mechanical energy into electrical energy.

Fig 3: Non-condensing Steam Turbine

DATA OF STEAM TURBINE

Data is taken from different loads of non-condensing steam turbine working at Hetero Infrastructure Sez LTD., Nakkapally(mandal), visakhapatnam (district),A.P.

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TABLE 1: STEAM DATA AT INLET

S.No	Load (MW)	Main Steam Flow(kg/s)	Main Steam Pressure (Kg/cm²)	Main Steam Temperature (°c)	Enthalpy of Inlet steam (kJ/kg)	Entropy of Inlet Steam (kJ/kg K)
1	2.6	6.97	59.4	473	3359.3	6.5
2	3.1	7.63	60.4	480	3374.9	6.85
3	4.4	11.3	62.5	483	3379.5	6.75
4	4.95	12.5	63.4	489	3392.85	6.73
5	5.5	12.83	63	491	3398.1	6.8
6	6.1	13.21	64	495	3422	6.7

TABLE 2: STEAM DATA AT EXHAUST

S.No	Load (MW)	Exhaust Steam Flow(kg/s)	Exhaust Steam Pressure (Kg/cm²)	Exhaust Steam Temperature (°c)	Enthalpy of Exhaust Steam (kJ/kg)	Entropy of Exhaust Steam (kJ/kg K)
1	2.6	6.194	3.5	210	2879.84	7.6
2	3.1	6.945	3.9	217	2892.78	7.23
3	4.4	10.56	4.2	226	2910.47	7.31
4	4.95	11.91	4	235	2930.4	7.3
5	5.5	12.44	4.3	240	2939.4	7.3
6	6.1	12.78	5.1	270	3064	7.4

ASSUMPTIONS:

- Ambient temperature and pressure are taken as 30°c and 1.013bar
- There is no steam loss across steam turbine.
- Gear box efficiency as per manufacturer is 98.40%
- Generator efficiency as per manufacture is 98.03%
- Exhaust steam from the turbine is utilised for further process in the industry.

STEAM TURBINE SPECIFICATIONS

- Manufacturer: Triveni Turbines
- Model Type: TST-1060-SB-037
- MAIN STEAM FLOW: 45TPH
- Normal steam pressure: 64 kg/cm^2
- Normal Steam Temperature: 495 °c
- Normal Exhaust Pressure: 5.1 kg/cm^2
- Normal Exhaust Temperature:270°c
- Number of stages: (1+5)/ (Impulse + Reaction)
- Governor Manufacturer: Woodward
- Governor Type: Electric & Hydraulic.

ANALYSIS

MODEL CALCULATIONS FOR LOAD OF 2.6MW:

A) ENERGY ANALYSIS:

1) Energy input at entry:

$$E_i = m_i * h_i$$
$$E_i = 6.97 * 3359.3$$
$$E_i = 23414.32 \frac{KJ}{s}$$

2) Energy output of heat exhausted:

$$E_o = m_{ext} * h_{ext}$$
$$E_o = 3.5 * 2879.84$$
$$E_o = 17837.73 \frac{KJ}{s}$$

3) Work done is equal to the energy in steam at entry to turbine minus steam at exit:

$$W.D = E_i - E_o$$
$$W.D = 23414.32 - 17837.73$$
$$W.D = 5576.592\ KW$$

4) Actual Power Develop by Turbine Shaft:

$$P = \frac{\text{Generator power}}{\eta_{(gearbox)} \times \eta_{(generator)}}$$
$$P = \frac{3500}{0.984 * 0.9803}$$
$$P = 3628.39\ KW$$

5) Energy Efficiency (1st Law of efficiency) of turbine:

$$\eta_I = \frac{\text{Actual Power Develop by Turbine Shaft}}{(E_{in} - E_{out})}$$
$$\eta_I = \frac{3628.39}{(23414.32 - 17837.73)}$$
$$\eta_I = 0.6506\ (or)\ 65.06\%$$

6) Heat rate of turbine:

$$H.R = \frac{\text{Net Heat Input}}{\text{Turbine Power}}$$
$$H.R = \frac{(E_{in} - E_{out}) * 3600}{3628.39}$$
$$H.R = \frac{(23414.32 - 17837.73) * 3600}{3628.39}$$
$$H.R = 5532.959 \frac{KJ}{KWh}$$

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B) EXERGY ANALYSIS:

1) Exergyinput:

$$\psi_{in} = m_s(h_s - T_o s_s)$$
$$\psi_{in} = 6.97[3359.3 - (307 * 6.5)]$$
$$\psi_{in} = 9505.686\frac{KJ}{s}$$

2) Exergy out:

$$\psi_{out} = m_s(h_{exh} - T_o s_{exh})$$
$$\psi_{out} = 6.194[2879.84 - (307 * 7.6)]$$
$$\psi_{out} = 3385.888\frac{KJ}{s}$$

3) Exergy destruction in turbine:

$$\psi_{des} = \psi_{in} - \psi_{out} - \psi_{power}$$
$$\psi_{des} = 9505.686 - 3385.888 - 3628.39$$
$$\psi_{des} = 2491.408\frac{KJ}{s}$$

4) Exergy Efficiency (2nd Law of efficiency) of turbine:

$$\eta = \frac{\psi_{power}}{\psi_{in} - \psi_{out}}$$
$$\eta = \frac{3628.39}{(9505.686 - 3385.888)}$$
$$\eta = 0.5528\ (or) 55.28\%$$

GRAPHICAL REPRESENTATION

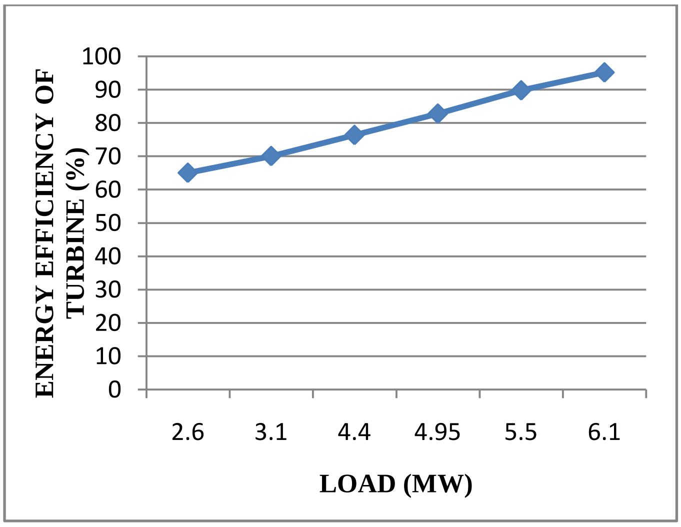

Fig 4: Graph between Load and Energy Efficiency of Turbine

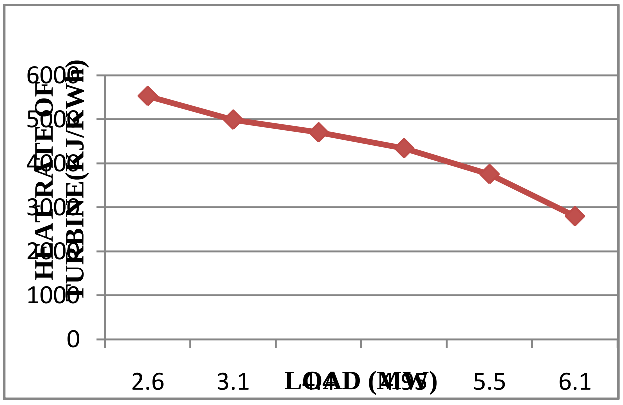

Fig 5: Graph between Load and Heat rate of Turbine

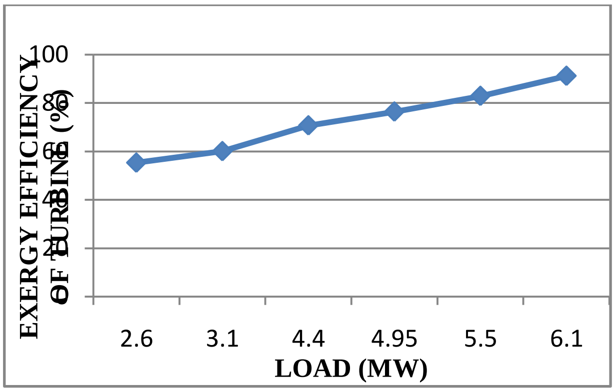

Fig 6: Graph between Load and Exergy Efficiency of Turbine

RESULTS AND DISCUSSIONS

TABLE 3: FINAL DATA OF ENERGY ANALYSIS

S.No	Load (MW)	Energy Input (KJ/s)	Energy Output (KJ/s)	Work done (KW)	Turbine Power (KW)	Energy Efficiency of Turbine (%)	Heat rate of Turbine (KJ/KWh)
1	2.6	23414.32	17837.73	5576.59	3628.39	65.06	5532.95
2	3.1	25750.79	20090.36	5660.13	4250.4	70.09	4794.01
3	4.4	38188.35	30734.56	7453.78	5701.75	76.4	4706.205
4	4.95	42410.63	34901.06	7509.56	6220.09	82.82	4346.3
5	5.5	43579.62	36566.14	7031.48	6738.43	89.8	3756.56
6	6.1	45204.62	39157.92	6046.7	7775.12	95.2	2799.715

TABLE 4: FINAL DATA OF EXERGY ANALYSIS:

S.No	Load (MW)	Exergy In(KJ/s)	Exergy Out(KJ/s)	Exergy Destruction In Turbine(KJ/s)	Exergy Efficiency (%)
1	2.6	9505.68	3385.88	2491.4	55.28
2	3.1	9704.97	2625.36	2829.21	60.03
3	4.4	14771.93	7036.128	2034.032	70.7
4	4.95	16584.25	8209.56	2154.59	76.4
5	5.5	16813.72	8686.52	1388.42	82.9
6	6.1	18032.97	10124.32	133.53	91.2

Experimental results show that power load on the steam turbine increases at different loads

- Turbine energy and exergy efficiency increases at different loads.
- The exergy efficiency is lower than the energy efficiency at different loads. This mainly due to thermal product, which is higher than electrical power, is delivered at a lower temperature.
- There is an improvement observed in the turbine that the turbine heat is rate is reduced and efficiency of the turbine increases.

CONCLUSION

Hence in the overall project we have worked on the performance of non-condensing steam turbine using energy and exergy analysis. Therefore the energy efficiency, exergy efficiency and turbine heat rate are evaluated based on the requirement of load demand.

- Turbine exergy efficiency is lower than the energy efficiency as utilization of heat is at lower temperature than inlet.
- Therefore this turbine efficiency increases for different loads. Thus the heat rate of turbine reduces to give better output to the turbine.
- This type of turbine gives better efficiency than other turbines.
- It is more advantageous to run the turbine in different environmental conditions.

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